CATHODE CHARACTERIZATION SYSTEM: PRELIMINARY RESULTS WITH (Ba,Sr,Ca)O COATED CATHODES

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Abstract

In this paper we report on the performance of a cathode characterization system for studying the emission parameters of thermal electron emitters. The system consists of vacuum chamber, power supplies and equipment for measuring and control. Measurements have been taken of the emission current as function of cathode temperature and anode voltage. Several $(Ba, Sr)O$ coated cathodes were tested and the results have shown good agreement with Child's and Richardson's laws. The experimental work function is between 1.0 and 2.0 eV. All emission parameters measured are consistent with international literature data.

1 Introduction

The main motivation for the 35 GHz, 100 kW gyrotron development program under way at INPE lies on the utilization of high power millimeter radiation for fusion plasma heating and current drive experiments [1],[2].

The INPE gyrotron electron gun is composed of a conical cathode with a thermal electron emitting band and two anodes (Fig. 1). This gun was designed to generate an electron beam with high transverse energy and low velocity spread [3]. This electron gun should operate at an adequate temperature to generate a total laminar beam current of 5 A. Considering the gun design details, the emission density of the cathode band is near 2.4 A/cm^2, for pulsed electric fields. Allowing for a minimal safety margin, an emitter which could provide at least 3.0 A/cm^2 current density is desirable. Furthermore, due to the large size of the cathode ($\sim$ 60 cm^2), the required emission should be available at as low a temperature as possible in order to minimize both the necessary heater power and to reduce radiating heating of surrounding gun components. The need for a high current density at a low operating temperature limits the available options to the very low work function thin film emitters.

During operation the temperature distribution on the electron gun may attain unfavourably high values which could give rise to severe problems. In this situation, the cathode, anode and emitter surfaces are likely to evaporate, thus increasing the possibility of an arcing to occur. Another constraint factor is the difference of thermal expansion betwecm the metal base and the coating material, that causes stresses at the interface and can result in the rupture of the film. In addition, the conical cathode shape poses difficulties in fabricating adequate self-sustaining cathodes.

Therefore, for preliminary gyrotron experiments, metal-oxide-coated cathodes will be

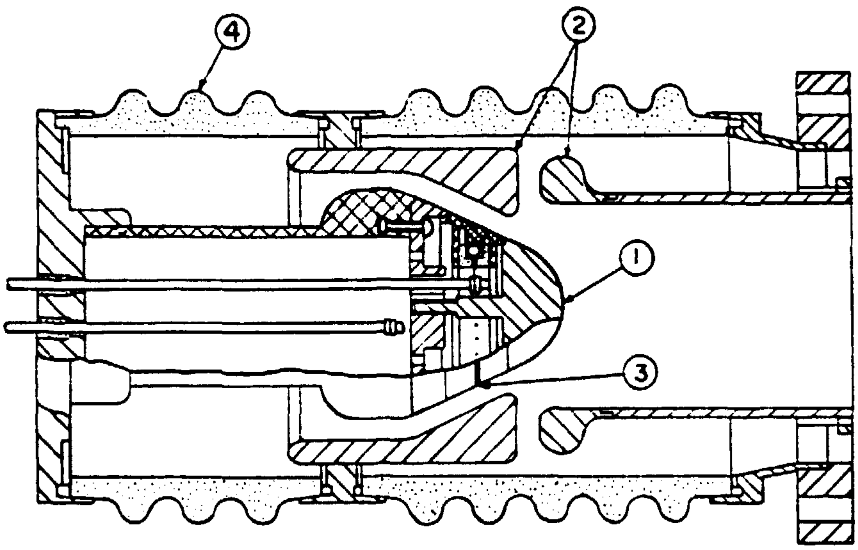


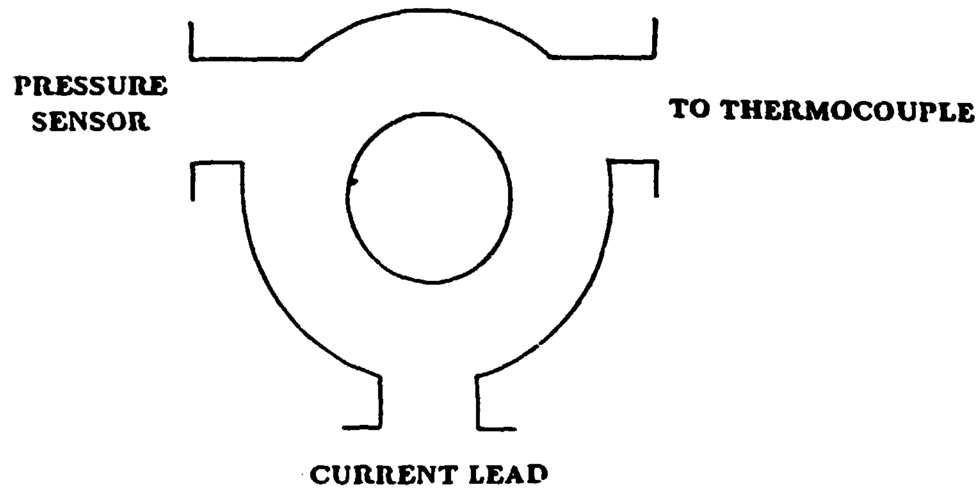
Figure 1. Gyrotron electron gun

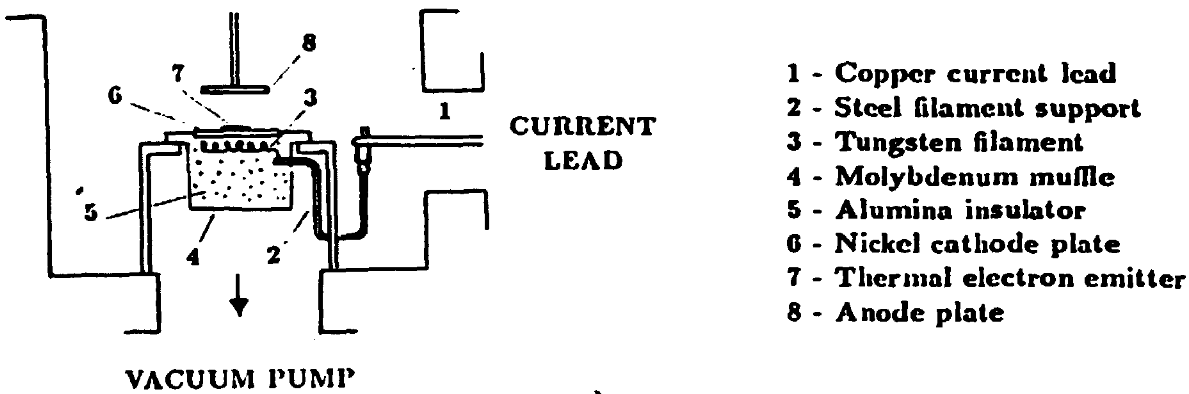
used. For the cathode development, work has been done to design and to fabricate a characterization system for emission test of the indirectly heated coated cathodes composed of oxide and/or cermet materials [4]. This characterization procedure involves obtaining the cathode emission characteristics for optimizing their chemical composition, fabrication processes, activation procedures, operating temperature and life time.

2 Assembling and Tests

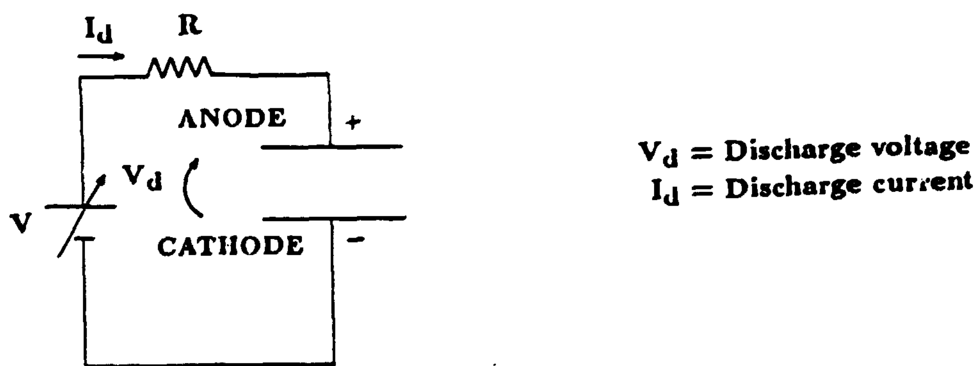
A cathode characterization system was assembled at LAP/INPE [5]. This system is composed of a vacuum chamber attached to a vacuum diffusion pump and sensors for operation at pressions near 2×10^{-6} torr. The cathode temperature is measured using a $Pt - 13\%Rh$ thermocouple connected to a temperature meter and the heating filament is heated by a 50 V, 50 A power source. The anode is polarized by a 300 V, 200 mA power source (Fig. 2). A helically wound tungsten filament 0.5 mm in diameter was used to heat the emitting surface. While the heating can be achieved by radiation alone, the thermal transfer was greatly improved by potting the filament in the cathode housing with alumina powder.

Several $(Ba, Sr, Ca)O$ coated cathodes have been prepared using a nickel plate as a metal base [4]. The carbonate suspensions had the following chemical composition: i) solid components from a equimolecular $BaCO_3$ and $SrCO_3$ powder mixture and ii) liquid components (binder) from 2.7% of nitrocellulose 32 sec., 21.7% of ethyl alcohol (dehydrated) and 75.6% of amyl acetate. The amount of solid components in the suspension is 28.6% (in weight). This is the adequate consistence for application by spray. So prepared suspension was deposited on nickel plate and dried at 110° C. After that treatment the plate with $(Ba, Sr, Ca)CO_3$ and binder was mounted on heating assembly. The next step was cathode activation which is the most important operation and was made in the following way: i) a low heating velocity ($\simeq$ 3° C/min) to permit the evaporation of organic components and carbonate decomposiiton to obtain a coating of $(Ba, Sr, Ca)O$ at 900-1000° C, and ii) activation itself and emisison due to partial reduction of the oxides at metal-coating interface to produce free barium within the coating by Ba^+ and Sr^+ diffusion.





a)



b)

Figure 2. Cathode characterization system: a) vacuum chamber and heating assembly and b) electric schematic diagram

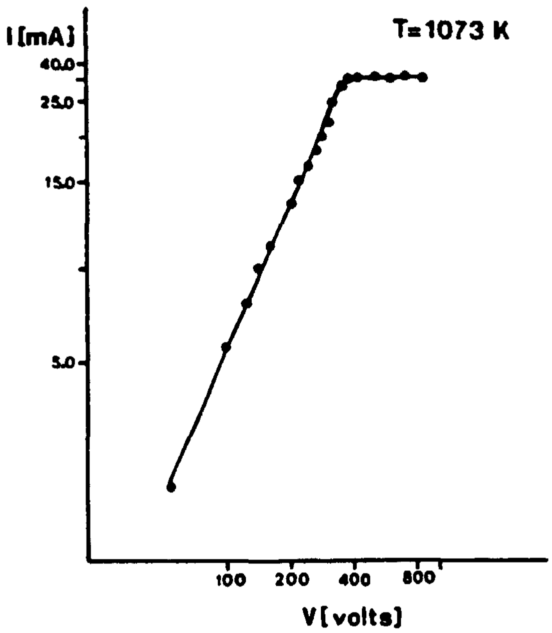


Figure 3. Current-voltage characteristics plotted as ln i versus V at constant cathode temperature

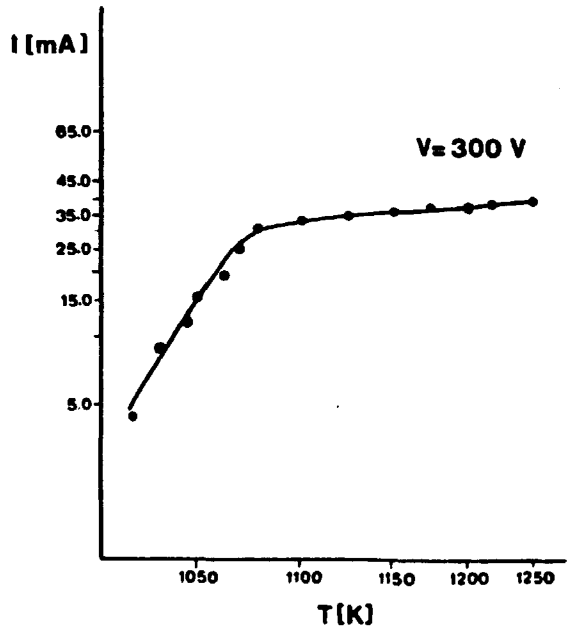


Figure 4. Current as function of temperature for constant voltage

3 Results and Discussion

The emission current dependence on both the anode voltage and cathode temperature is used for characterization of the thermal electron emitter [4],[6]. For these measurements a diode consisting of barium-strontium-calcium oxide cathode with 6 mm in diameter located at a 5 mm distance from the anode was used.

Fig. 3 shows current-voltage characteristics measured at constant temperature. The curve follows the three-halves power Child's law $i \sim V^{3/2}$ up to the saturation voltage. This dependence so far attained does emply that good electron emission all over the cathode area has been achieved. Above voltage saturation, the anode current breaks off gradually and the slight continued increase is due to a reduction of the work function by the applied voltage as described by the Schottky effect.

Fig. 4 shows the measured current as function of cathode temperature for a constant voltage of 300 V. The straight line, up to the saturation temperature, follows the Richardson's equation

$$J = A_o T^2 e^{-\phi/kT} \tag{1}$$

where J is the satured thermal emission current density, A_o is Dushman's constant (to be determined later), T is the cathode temperature in degrees Kelvin, k is Boltzmann's constant (8.6×10^{-5} eV/K) and ϕ denotes the true work function in eV which gives the maximum potential energy of an electron at the emitting surface. Notice that Richardson's equation applies only when all emitted electrons reach the anode, i.e., under temperature-limited-operation. The quantities ϕ and A_o in eq. (1) are used for cathode characterization. To this end, the experimental values of $ln\ J/T^2$ are plotted against $1/T$ and a straight line is obtained as shown in Fig. 5. The slope of this line is a measure of ϕ/k and the intercept at $1/T = 0$ gives the constant A_o. The values of ϕ and A_o thus calculated are, respectively, 1.3 eV and 2.5 A/m²/K². Such a work function value is consistent with the emisson characteristics of oxide cathodes, as the oxides of barium, strontium, and calcium all have ϕ's between 1.0 and 2.0 eV [4].

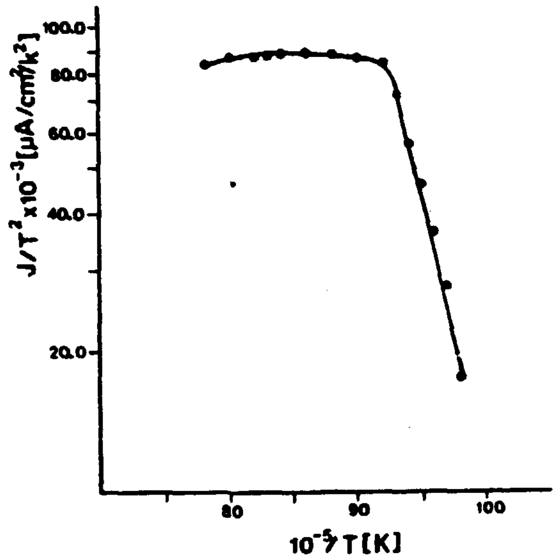


Figure 5. Richardson plot for experimental data

4 Conclusion

For future development of thermal electron emitters to be used in the INPE gyrotron, a cathode characterization system has been designed and assembled. An oxide-coated cathode was fabricated and preliminary results included measurements of emission current as function of cathode temperature and anode voltage. Good capability of this cathode has been demonstrated and forthcoming data will be used to establish life endurance models relevant to microwave tube applications.

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